Position detection with Frequency Smoothing

Field of the Invention

The invention relates to a method for calculating a
position of a mobile communications equipment, in
particular a mobile phone. The invention further relates
to a mobile communications equipment able to calculate a
position. The invention also relates to a system for
calculating a position of a mobile communications
equipment as well as a module, a computer program and a
computer program product for calculating a position of a
mobile communications equipment.

Background of the Invention

Position detection is a known method in third generation
mobile communication. In particular for code division
multiple access (CDMA) mobile stations (MS), position
detection using Advanced Forward Link Trilateration
(AFLT) is known.

Advance Forward Link Trilateration is a geolocation
technique utilizing the time difference of arrival
(TDOA) or a time of arrival (TOA) of radio signals from
the base stations measured by mobile stations.

To allow calculation of the position of mobile stations,
in particular a code phase is detected. The code phase
may be the fraction of the code period that has elapsed

since the latest code boundary. By using the code phase, the time of arrival or the time difference of arrival can be calculated.

Cellular network-related wireless location methods can be subdivided into three categories according to the mobile station and network functionalities. These three categories are pure network-based methods, MS-assisted network-based methods, and MS-based network-assisted methods.

For a pure network-based method, the network fulfills all the positioning functionalities including location measuring and position calculations. An MS itself does not take any active part in the process. Obviously, these methods are applicable to legacy cellular phones. However, the network may require some modifications to accommodate a wide range of hardware products.

The second category, MS-assisted network-based methods, consists of methods, which require at least some *active* participation from the MSs. An MS can take part in location measuring or doing some other positioning-dedicated tasks, while most of the positioning functionalities are still completed in the network. The role of an MS is solely to assist the network in positioning.

In MS-based network-assisted methods, the roles of the MSs and the cellular network are reversed in comparison to those in the second category method. An MS makes location measurements and calculates its own position. Thus, the role of the network is simply to assist MSs in

location estimation. Methods of this type enable a
denser position-fixing rate.

The simplest method for locating a cellular phone is
CELL-ID, which is based on cell identification. An MS
can be assigned a location if the cell in which the MS
is located can be identified. Since this is an inherent
feature of all cellular systems, minimal changes to
existing systems are needed. A cell only has to be
associated with a location, such as by association with
the coordinates of the base station of this cell.

This method boasts the additional advantage that no
calculations are needed to obtain location information.
Thus, the CELL-ID based method is fast and suitable for
applications requiring high capacity. However, the
drawback is that accuracy depends directly on cell
radius, which can be very large, especially in rural
areas.

To allow position detection, geological techniques like
time difference of arrival and time of arrival are
known.

Applying these techniques requires that the number of
measurements is adequate to make an accurate estimation
of the mobile station location. For instance, it is
required that at least three TDOA measurements are
available for uniquely determining the MS position.
However, the underlying communication system is designed
to reduce the interference by maintaining the
transmission powers of the MSs and BSs at a minimum
required level in order to accommodate more users.
Consequently, only when the MS is at the edge of a cell,

may it obtain enough measurements for location estimation. This is known as the hearability problem.

The angle of arrival (AOA)-based location method is one of the oldest positioning methods. Its early use began during the development of radar, sonar, and antenna array techniques. By means of array signal processing techniques, the direction of an MS with respect to BSs can be measured at BSs. Thus, the MS is at the intersection of the lines derived from AOA measurements. The accuracy of the AOA method is dependent on the distances between the MS to be located and the antenna arrays at BSs. The further the MS is from the antenna arrays, the larger is the positioning uncertainty. Non-line-of-sight (NLOS) signal propagation is a significant source of inaccuracy. When NLOS components exist, AOA measurements will be distorted, thus resulting in degraded positioning accuracy.

The measurements required in Time of Arrival (TOA) methods are the absolute signal transmission times between MS and BSs that are equivalent to MS-BS distances. The MS is located at the intersection of several circles, of which the centres are the BSs used, and the radii are the measured MS-BS distances. At least three TOA measurements are required to uniquely determine the 2-D position of an MS.

TOA wireless location methods require that all base stations (BS) be precisely synchronized to each other and that the MS to be located be synchronized to the network as well. For this reason, TOA positioning is feasible only in fully synchronized networks; for example, in IS-95 CDMA systems.

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The measurements in Time Difference of Arrival (TDOA) methods are relative signal transmission times, which are equivalent to distance differences. A TDOA measurement defines a hyperbola with two BSs as the foci. At least three hyperbolae are needed for unique MS position determination.

A TDOA method requires that all base stations involved be synchronized. This can be done either by synchronizing all BSs physically, or by bringing all BSs to a common reference time by measuring time differences between BSs. MSs do not need to be synchronized since the MS clock bias is the same with respect to all BSs and differencing any two TOA measurements will cancel out the MS clock bias. It may also be possible to provide the BSs with a time reference from a satellite based positioning signal, such as GPS.

In a CDMA System, a pilot phase signal is continuously transmitted. This signal allows mobile stations to detect the presence of CDMA channels and provides timing information for demodulation. According to mobile communication standard, the pilot signal is a DS spread spectrum signal. The spread function is a zero Walsh function. The signal is further modulated by a pseudo noise (PN) sequence of a particular base station. The pseudo noise sequences of different base stations only differ in an offset, which is a multiple of 64 pseudo noise chips.

In particular, there are 64 physical channels in the forward link of an IS-95 CDMA cellular system; these are distinguished by the 64 orthogonal Walsh functions,

which serve as digital carriers. These physical channels form four types of logical channels.

First, the pilot channel is identified by Walsh function zero. It continuously broadcasts a known signal to provide the MSs a robust time, frequency, and phase reference for demodulation in other channels.

The pilot channel possesses dominant transmission power. Approximately 15-20% of the maximum transmission power of a BS is dedicated to the pilot channel to ensure the visibility of the pilot signal over the coverage area. This also makes pilot signals more easily acquired from neighboring cells as well. The pilot signal is a known continuous broadcasting signal. It enables an MS to keep locked on the pilot Pseudo Noise (PN) code. All BSs transmit the same PN sequence but with different offsets. This makes it easier in the search process of a receiver to acquire TDOA measurements.

The process of generating a pilot signal provides a zero Walsh function with a chip rate of 1.2288 Mcps (mega chips per second). It is first modulated by the pilot baseband "data". Then, this intermediate signal is separated into an I-component and a Q-component to further modulate the I-channel PN sequence and the Q-channel PN sequence. Wave shaping, amplification, and RF carrier modulation are finally conducted to generate the actual signal transmitted to MSs.

The Walsh code is one type of orthogonal code. It is used in IS-95 CDMA systems to separate different physical channels. Both the I-channel PN sequence and the Q-channel PN sequence are maximal length sequences

generated by 15-stage shift registers and lengthened by
the insertion of one chip per period in a specific
location in the sequences. Thus, the sequence length is
in chips. Each base station is distinguished by a
different phase offset in both the I-channel and the Q-
channel PN sequences. The offset is a multiple of 64 PN
chips, which yields 512 possible 64-chip offsets. At a
rate of 1.2288 Mcps, the I-sequence and Q-sequence
repeat every 26.66 ms, or 75 times every 2 seconds.

The synchronization channel is identified by a Walsh
function, and is a continuously broadcasting channel. It
provides MSs with BS timing information, cell site
identification number, and other information for
synchronization.

In addition, there can be up to seven paging channels. A
paging channel contains paging messages and conveys
other control messages from the BSs to the MSs.

Eventually, there are at least 55 traffic channels. They
carry user information. They also carry control messages
using "blank and burst", which is a time multiplexing
technique used on traffic channels to send overhead
signaling or (optionally) secondary traffic in which a
frame of primary digital voice data is blanked, i.e.,
not transmitted to allow the overhead or secondary
traffic to be transmitted at a 9600 bit/second rate. In
the blank-and-burst format, a frame or frames of primary
digital voice data are suppressed or not transmitted to
make time available to send signaling traffic. The
digital voice frames are lost. However, the degradation
of the recovered analog voice is minimal provided not
too many frames are blanked consecutively. Typically,

the transmitter controllers wait for a less-than-full-rate Vocoder frame in which signaling traffic can be multiplexed with voice traffic without the loss of any voice bits.

Multiplexing signaling with voice in less-than-full-rate frames is called dim and burst, which is a time multiplexing technique used on traffic channels to send overhead signaling or (optionally) secondary traffic in which a less-than-full-rate frame of primary digital voice data and overhead or (optionally) secondary traffic data are combined and transmitted at a 9600 bit/second rate.

To allow location estimation, a method called forward link location is known. Reception on forward link location is performed coherently. To maintain coherence, the MS searches for and locks onto a pilot pseudo noise (PN) sequence. Every base station sector broadcasts the pilot PN sequence with a unique known offset, as previously described. The base stations are synchronized, allowing the MS to identify the signal originating from a particular BS sector.

A common IS-95 mobile terminal has four rake receiver fingers, three of which are used to receive an incoming signal and one to search for multipath signals and handover candidates. During operation, the terminal keeps track of the strongest pilot channel in its vicinity. When requested by the BS through a pilot measurement request order (PMRO), the BS will report all pilot signals it receives above a given threshold. The message sent back to the BS includes the magnitude of

each pilot, relative to the offset of the base station transmitting the pilot signal.

The pilot signal may be used within the BS as phase reference. Knowing the PN offsets of the pilots transmitted from nearby BSs it is possible to construct TDOA estimates for the BS. As long as the MS is able to detect at least three pilot signals from three different BSs, the location estimation may be possible.

The main problems in location estimation using these methods are synchronization errors in the BSs. These errors result from poor PN resolution and multipath or non-line-of-sight propagation of the received signals.

In particular the specifications 3GGP2 C.S0022-0, v1.0, "Location Service (position determination service)", and 3GPP2 C.S0036-0, v.0, "Recommended Minimum Performance Specifications for C.S0022-0 Spread Spectrum Mobile Stations" describe methods allowing code division multiple access (CDMA) systems to calculate positions of mobile equipment. Depending on where the position calculation is performed, the method may either be mobile station based or mobile station assisted. In a mobile station based solution, the position may be calculated within the mobile phone itself. In the mobile station assisted case, a position may be calculated in a network server, in particular in a position determination entity. The position determination entity may use for its position calculation information provided by the mobile station, in particular phase and time measurements reported by the mobile station.

To allow calculation of a position using a time of
arrival or a time difference of arrival method, at least
three different pilot phase signals and pilot phase
measurements should be provided. The pilot phase
measurements are carried out within the mobile stations.

For position calculation within the mobile station,
assistance data from the network is required. This
assistance data may include the co-ordinates of the
reference and neighboring base stations together with
their time corrections.

A drawback of known AFLT position measurements using
pilot phase measurements is that the pilot phase signal
is subject to noise. The noise level causes the pilot
phase signal to be disturbed, thus deteriorating the
measured pilot phase.

Summary of the Invention

The invention tries to improve the position calculation
by measuring a signal phase of said first signal code
within said mobile communications equipment, measuring a
carrier signal within said physical communications
channels within said mobile communications equipment,
reducing a noise level of said measured signal phase by
using said carrier signal, and calculating said position
of said mobile communications equipment using at least
said noise level reduced signal phase.

The mobile communications equipment according to the
invention may be a mobile station such as a mobile
phone.

According to embodiments, the invention provides using pseudodoppler measurements for smoothing a code phase measurement in particular in an advanced forward link trilateration environment. The method for smoothing the measured signal phase as such is already known for global positioning signal receivers for carrier smoothing, in particular from "High-Precision GPS Navigation with Emphasis on Carrier-Phase Ambiguity Resolution", Lachapelle, et.al, Marine Geodesy, Volume 15, pp. 253-269, 1992, Taylor&Francis.

Pseudodoppler frequency may be understood as the measured Doppler frequency shift received from the communication signal, such as a CDMA signal, received from a base station. Since the transmitter (Base station) and receiver (mobile station) clocks are not synchronized and are subject to drifts, it is referred to as pseudodoppler.

By reducing the noise level of the pilot phase measurement, the quality of position calculation will become more accurate. The smoothed pilot phase measurements will also be more robust against multipath propagation phenomena or other channel impurities.

Carrier smoothing may probably not allow improving position detection. If there are not enough measurements or if the geometry of the base stations is not favorable for position calculation, pseudodoppler measurements probably will not change the situation. However, it is proposed that pseudodoppler measurements are used in improving the quality of pilot phase measurements by reducing the noise of the pilot phase measurements. The

noise may be induced by thermal noise, interferences, multipath, etc., which may be reduced by filtering the pilot phase measurements with pseudodoppler frequency.

For calculating said signal phase, a pilot channel may be used. A pilot channel may be an unmodulated, direct-sequence spread spectrum signal transmitted by a CDMA base station or a mobile station. A pilot channel provides a phase reference for coherent demodulation and may provide a means for signal strengths comparison between base stations for determining when to hand-off. A pilot phase offset may be the time difference measured at the mobile station between the earliest arriving useable multipath component of a pilot and the mobile station system time reference.

To obtain the pseudodoppler frequency it is proposed that the phase of said first signal code phase is tracked and said pseudodoppler frequency is obtained from a carrier and/or phase tracking loop. According to another embodiment the pseudodoppler frequency is obtained from matched filter outputs within said mobile communications equipment.

According to yet another embodiment the pseudodoppler frequency is obtained from accumulated carrier phase measurements from a carrier phase tracking loop. Accumulated carrier phase measurement is obtained by integrating the output of the carrier phase tracking loop for a period of time, typically for the time between two code phase measurements (measurement interval). Accumulated carrier phase provides by far the most accurate estimate of the average Doppler frequency between two measurement instances if carrier

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phase lock has been maintained during the accumulation time without cycle slips. Average Doppler frequency (pseudodoppler) can be calculated by dividing the accumulated carrier phase by the accumulation time.

According to an embodiment, said physical communication channels are transmitted from ground based base stations.

To allow calculating the position within the mobile network, it is proposed that said measured signal phase is transmitted from said mobile communications equipment to a base station.

To allow smoothing of the measured pilot phase within the mobile communications network, it is proposed that said measured pseudodoppler frequency is transmitted from said mobile communications equipment to said base station.

Providing all available and measured information from the mobile station to the base station allows calculating said position within an underlying communications network, or even within a server remotely attached to said network, such as delivering the data to the server via the Internet.

To calculate the position based on the distance of a mobile station, it is possible to use a time of arrival calculation principle, as proposed in the CDMA protocol.

It is also possible to use a time difference of arrival calculation principle.

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To assist the mobile station in calculating the
position, it is proposed that at least position
information of said base station is transmitted from
said base station to said mobile communications
equipment. Furthermore, time corrections of the base
stations may be transmitted.

One possible signal for phase measurement may be a pilot
signal code, as proposed in the CDMA protocol.

To facilitate position detection, it is proposed that
said base station and said mobile equipment utilize a
code division multiple access communication protocol.
Within this protocol, advanced forward link
trilateration is already described.

A hybrid position calculation may facilitate different
methods for position estimation. This may be combining
position estimation from Global Navigation Satellite
Systems, such as, GPS, Galileo, GLONASS GNSS and
position estimation from AFLT measurements. Also any
other combination of AFLT measurements with any position
estimation using cellular network measurements, Wireless
Local Area Network (WLAN), and/or BlueTooth network
measurements are possible. Other cellular network
measurements may be for example, round-trip time
measurement, RX-level, Cell Identity, sector
information, etc.

The invention will be described in greater detail in the
following figures.

Brief Description of the Drawings

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Fig. 1   shows a first flowchart;

Fig. 2   shows a second flowchart;

Fig. 3   shows a system for position detection; and

Fig. 4   shows an inventive mobile station.

Detailed Description of the Invention

Figure 1 depicts a flowchart of messages exchanged
between a mobile station 2 and base station 4. Depicted
are only messages between one base station 4 and one
mobile station 2, however, to allow position
calculation, at least three base stations 4 have to
provide signals to one mobile station 2.

Base station 4 provides mobile station 2 with pilot
signals 8. The pilot signals 8 are transmitted from base
station 4 to mobile station 2 in frequent intervals.
Together with pilot signal 8, further position and
timing information of base station 4 are transmitted to
mobile station 2. These may be the position of base
station 4, possibly retrieved from a GPS signal received
within the base station, as well as their time shift.
The base station 4 may be synchronized with other base
stations using a GPS time reference received in the base
stations.

Receiving the pilot signal 8 in mobile station 2 allows
mobile station 2 to calculate a pilot phase within step
12. This may be done by comparing the phase of pilot

signal 8 with a clock reference in the mobile station 2.
A clock reference in mobile station 2 corresponds to a
clock reference in base station 4, thus a phase shift in
pilot signal 8 may be detected in mobile station 2. The
pilot signal 8 is transmitted to said mobile station 2
together with further signals 10, such as
synchronization channel, paging channels, or traffic
channels. These channels may be utilized to obtain a
pseudodoppler frequency.

The pilot phase measurement may be inaccurate due to
signal noise. Therefore, mobile station 2 may obtain a
pseudodoppler frequency. This may be done by tracking
the phase of said first signal code phase and said
pseudodoppler frequency is obtained from a carrier
and/or phase tracking loop. The pseudodoppler frequency
may also be obtained from matched filter outputs within
said mobile communications equipment.

The pseudodoppler frequency is acquired in step 14
within mobile station 2. Using pilot phase and
pseudodoppler frequency, the mobile station 2 may
calculate its position in step 16.

To reduce a noise level of said measured signal phase,
it is proposed that said noise level is reduced by
smoothing the noise level by estimating the signal phase
using said pseudodoppler frequency. Because the noise of
the signal phase measurement is much larger compared to
the pseudodoppler noise, it is advantageous to smooth
the pilot phase measurement with the pseudodoppler
measurement. The pseudodoppler measurements are used in
smoothing by estimating the carrier phase measurements
with pseudodoppler frequency. This may be done by

$$\rho_{sm}(k) = \omega_{sm}(k) \times \rho_{AFLT}(k) + (1 - \omega_{sm}(k)) \times \lfloor \rho_{sm}(k-1) + f_{Dopp}(k) \times \Delta T_{AFLT}(K) \rfloor$$

where

$\omega_{sm}(k) = $ smoothing gain,

$\rho_{AFLT}(k) = $ measured pilot phase at time k,

$\rho_{sm}(k) = $ smoothed pilot phase at time k,

$f_{Dopp}(k) = $ pseudodoppler frequency measurement at time k and

$\Delta T_{AFLT}(k) = $ time difference between two AFLT measurements at time k.

To allow providing a minimum smoothing weight, it is proposed that the smoothing gain is reduced as

$$\omega_{sm}(k) = \begin{cases} \omega_{sm}(k-1) - 0.01, & \text{if } \omega_{sm}(k-1) > \varpi_{sm} \\ \varpi_{sm}, & \text{otherwise} \end{cases}$$

where ϖ_{sm} is a threshold value for the minimum smoothing weight. It is recommended that ϖ_{sm} will never be zero. Non-zero values will make the smoother leaky, so that pilot phase smoothing will never purely be based on pseudodoppler measurements. However, the above equations do only represent one possible smoothing algorithm. Numerous other algorithms for smoothing the AFLT pilot phase measurements with pseudodoppler frequency are possible.

The calculated position may be provided to base station 4 with a position message 18.

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According to embodiments the pseudodoppler frequency is obtained from accumulated carrier phase measurements from a carrier phase tracking loop. Accumulated carrier phase measurement is obtained by integrating the output of the carrier phase tracking loop for a period of time, typically for the time between two code phase measurements (measurement interval). Accumulated carrier phase provides by far the most accurate estimate of the average Doppler frequency between two measurement instances if carrier phase lock has been maintained during the accumulation time without cycle slips. Average Doppler frequency (pseudodoppler) can be calculated by dividing the accumulated carrier phase by the accumulation time.

The depicted method may be carried out within frequent intervals or upon request. Depicted is only one interval.

A method for calculating a position of a mobile phone using advanced forward link trilateration, by receiving physical communication channels with the mobile communications equipment, receiving first signal codes within physical communication channels, measuring a signal phase of said first signal code within said mobile communications equipment, measuring a pseudodoppler frequency within said physical communications channels within said mobile communications equipment, smoothing said pilot signal phase by using said pseudodoppler frequency, and calculating said position using at least said smoothed pilot signal phase is provided according to embodiments.

Figure 2 depicts position calculation within the mobile
network. Figure 2 corresponds to Figure 1 up to step 14.
In mobile station 2 pilot phase measurements and
pseudodoppler frequency are available. This information
is provided within a position message 20 to base station
4. Using the pilot phase information and the
pseudodoppler frequency, base station 4 calculates the
position of mobile station 2 in step 22.

Figure 3 depicts a system allowing position calculation
with pilot phase smoothing using pseudodoppler
frequency. Depicted is mobile station 4 in a cellular
network comprising base stations 2. Mobile station 4
receives and transmits communication signals comprising
physical communication channels to and from base
stations 2, comprising pilot phase signals,
synchronisation channels, paging channels and/or traffic
channels. These channels may carry position information
and position measurements information.

The signals, in particular CDMA signals, are doppler
shifted, whereby the time references of the BS 2 and the
mobile station 4 are shifted, thus resulting in a
pseudodoppler frequency.

Using the pseudodoppler frequency together with the
pilot phase provided from the base station 2, mobile
station 4 may calculate its position or provide base
station 2 with position information enabling base
station 2 to calculate the position of mobile station 4.

Figure 4 depicts a mobile station 2 being able to
calculate its position using a pilot phase measurement
and a pseudodoppler frequency received from a CDMA base

station. Reception means 24 allow receiving CDMA signals. The CDMA signals may comprise a pilot signal. The CDMA signals are provided to signal processors 28, 30.

Signal processor 28 calculates a pseudodoppler frequency from the CDMA signal.

The CDMA signals are also provided to signal processor 30. Within signal processor 30, a phase shift of the pilot signal is measured. The phase of the pilot signal as well as the pseudodoppler frequency of the CDMA signal are provided to calculation means 32. Within calculation means 32, a noise level of said pilot phase is reduced by smoothing this signal with the pseudodoppler frequency. The resulting signal is used for calculating a position of the mobile station 2 within position calculation means 34.

The signal processors 28, 30, the calculation means 32 and the position calculation means may be encapsulated within a module 36. This module may be provided in the mobile communication equipment if required for improved position calculation.

Not depicted but also possible is to provide the information obtained in signal processors 28 and 30 via CDMA reception means 24 to a base station. Within the base station the position of mobile station 2 is then calculated.

According to embodiments a mobile communications equipment is provided comprising reception means for receiving a physical communication channels, a first

signal processor for measuring a signal phase of a first signal code within said physical communication channels, a second signal processor for calculating a pseudodoppler frequency within said physical communications channels, and calculation means for calculating a noise level reduced signal phase by using said pseudodoppler frequency.

In addition, according to embodiments, a mobile communications equipment is provided comprising reception means for receiving a physical communication channels, a first signal processor for measuring a signal phase of a first signal code within said physical communication channels, a second signal processor for calculating a pseudodoppler frequency within said physical communications channels, calculation means for calculating a noise level reduced signal phase by using said pseudodoppler frequency, and position calculation means for calculating said position using at least said noise level reduced signal phase.

In addition, a system for calculating a position of a mobile communications equipment is provided comprising in particular a mobile phone, and at least one ground based base station providing physical communication channels comprising a first signal code, at least one mobile communications·equipment, wherein said mobile communications equipment comprises a first signal processor for measuring a signal phase of a first signal code within said physical communication channels, a second signal processor for calculating a pseudodoppler frequency within said physical communications channels, and calculation means for calculating a noise level

reduced signal phase by using said pseudodoppler frequency, is another aspect of the invention.

A computer program and a computer program product for calculating a position of a mobile communications equipment, operable to cause a processor of a mobile communication equipment, as depicted in Figure 4 to receive physical communication channels within the mobile communications equipment, receive first signal codes within said physical communication channels, measure a signal phase of said first signal code within said mobile communications equipment, measure a pseudodoppler frequency within said physical communications channels within said mobile communications equipment, and reduce a noise level of said measured signal phase by using said pseudodoppler frequency, is another aspect of the invention.

The invention allows a more accurate position detection of a mobile station by smoothing a detected phase signal using a pseudodoppler frequency of a CDMA signal.